Environmental radioactivity in Greenland in 1975

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DRINKING WATER
STRONTIUM 90

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July 1976 Risø Report No. 347

Environmental Radioactivity in Greenland in 1975

by

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Research Establishment Risø
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Abstract

Measurements of fall-out radioactivity in Greenland in 1975 are reported. Strontium-90 (and Caesium-137 in most cases) was determined in samples of precipitation, sea water, vegetation, animals, and drinking water. Estimates are given of the mean contents of ^{90}Sr and ^{137}Cs in the human diet in Greenland in 1975.

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ABBREVIATIONS AND UNITS

FP	fission products
pCi	picocurie, 10^{-12} Ci, μμCi
nCi	nanocurie, 10^{-9} Ci, mμCi
mCi	millicurie, 10^{-3} Ci
S.U.	pCi ^{90}Sr/g Ca
M.U.	pCi ^{137}Cs/g K
nSr	natural (stable) Sr
S.D.	standard deviation, $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{(n-1)}}$
S.E.	standard error, $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{n(n-1)}}$
S.S.D.	sum of squares of deviation, $\Sigma(\bar{x}-x_i)^2$
f	degrees of freedom
s^2	the variance
v^2	the ratio between the variance in question and the residual variance
P	the probability fractile of the distribution in question
$\bar{x}$	mean value
η	coefficient of variation, relative S.D.
Σ	sum
anova	analysis of variance
A	η = 20-33%
B	η > 33%
B.D.L.	below detection limit

1. INTRODUCTION

1.1.

In 1975 the sampling programme was similar to that used in previous years but for a few minor modifications.

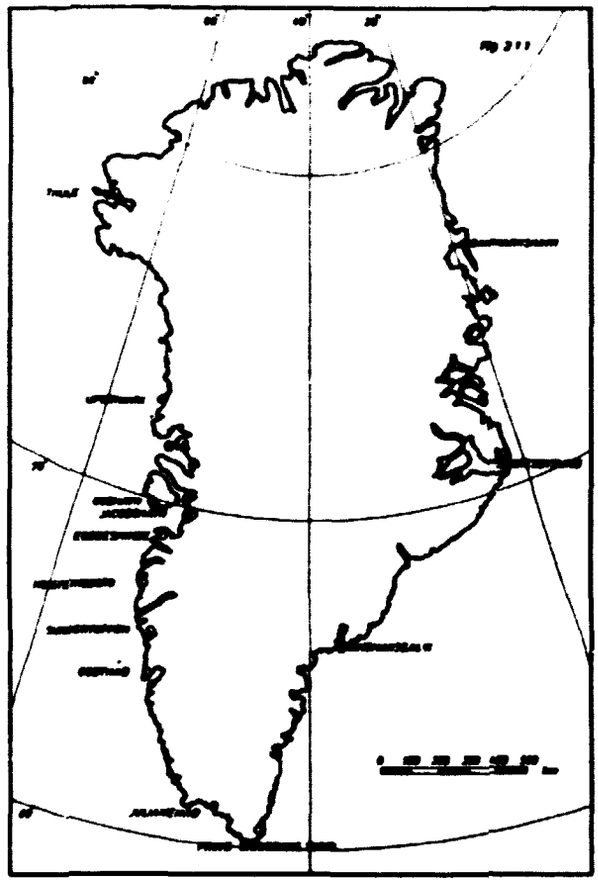

Fig. 1. Greenland.

1.2.

As hitherto, samples were collected through the local district physicians and the heads of the telestations. However, as it was impossible to obtain all samples specified in the programme, a number of samples were obtained from the Royal Green-

land Trade Company. Sea water samples were collected by the DANA.

1.3.

The estimated mean diet in Greenland was the same as that in 1962, i.e., it agreed with the estimate given by Professor E. Hoff-Jørgensen, Ph.D.

1.4.

The environmental studies in Greenland were carried out together with corresponding investigations in Denmark (cf. Risø Report No. 345)[2] and in the Faroes (cf. Risø Report No. 346)[3].

1.5.

The present report does not repeat information concerning sample collection and analysis already given in ref. 1.

2. RESULTS AND DISCUSSION

2.1. Strontium-90 in Precipitation

Table 2.1.1 shows the results of the measurements.

The ^{90}Sr concentrations in 1975 at the Greenland stations were 0.6 times the 1974 figures. In Denmark[2] and the Faroes[3] the fall-out levels decreased similarly from 1974 to 1975. Due to large amounts of precipitation in 1975 the Greenland mCi ^{90}Sr km^{-2} levels were nearly equal to the 1974 data.

Table 2.1.1

Strontium-90 in precipitation collected in Greenland in 1975

Location	Unit	Jan.-Mar.	Apr.-June	July-Sep.	Oct.-Dec.	1975
Upernavik	pCi/l	0.87 B	1.46 A	0.84	0.52	$\bar{x}$ 0.84
Σ 270 mm	mCi/km^2	0.020 B	0.042 A	0.137	0.029	Σ 0.228
Godhavn	pCi/l	1.33	1.23	0.34 A	0.39 A	$\bar{x}$ 0.65
Σ 424 mm	mCi/km^2	0.057	0.120	0.070 A	0.029 A	Σ 0.276
Godthåb	pCi/l	0.75	1.22	0.89	0.39	$\bar{x}$ 0.76
Σ 698 mm	mCi/km^2	0.110	0.121	0.217	0.081	Σ 0.529
Prins Chr.Sund	pCi/l	0.91	(1.28)**	0.31 B	0.45	$\bar{x}$(0.79)
Σ 2960* mm	mCi/km^2	(0.646)	(1.119)	(0.112)B	(0.453)	Σ(2.330)
Kap Tobin	pCi/l	0.69 B	0.61 B	0.49 A	0.08	$\bar{x}$ 0.38
Σ 318* mm	mCi/km^2	(0.052)B	(0.016)B	(0.043)A	(0.010)	Σ(0.121)
Danmarkshavn	pCi/l	(0.77)**	2.03 B	(0.47)**	0.14 B	$\bar{x}$(0.58)
Σ 73* mm	mCi/km^2	(0.015)	(0.014)B	(0.009)	(0.004)B	Σ(0.042)

* The missing amount of precipitation was kindly supplied by Mr. Gunnar Nielsen, Danish Meterorological Institute

**Estimated from VAR3[2].

Table 2.1.2

Analysis of variance of ln pCi ^{90}Sr/l precipitation in Greenland 1975 (from table 2.1.1)

Variation	SSD	f	s^2	v^2	P
Betw. quarters	7.191	3	2.397	8.72	>99.5%
Betw. locations	1.723	5	0.345	1.25	-
Remainder	3.298	12	0.275		

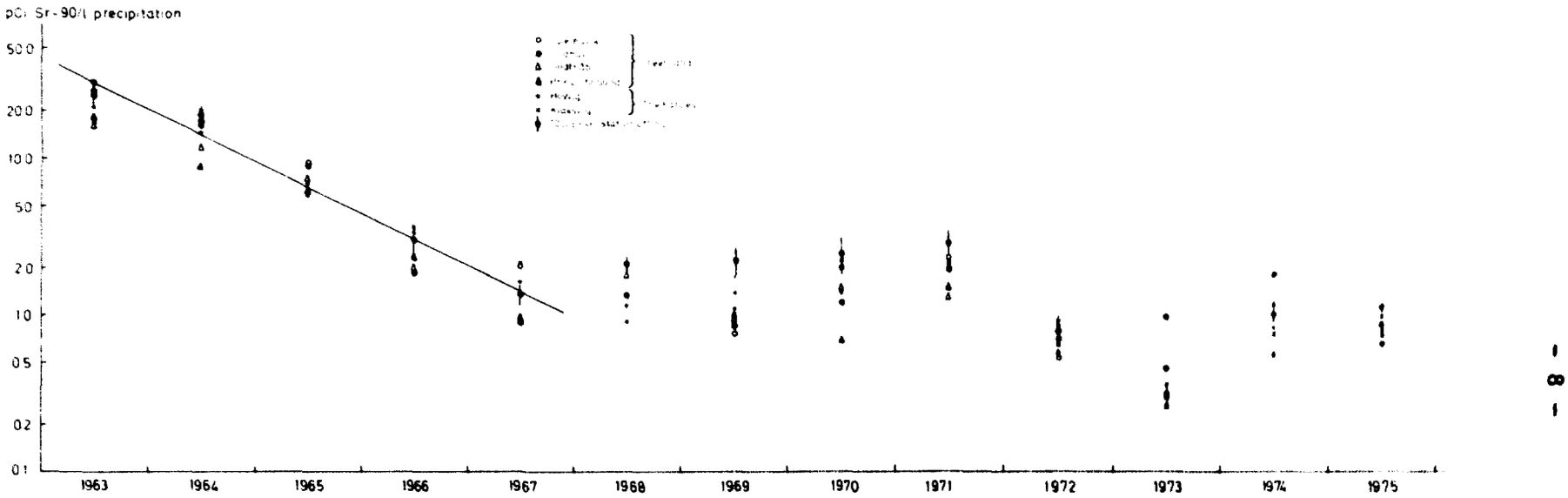

Fig. 2.1.2. Annual specific mean activity of ^{90}Sr in precipitation collected in Denmark, the Faroes, and Greenland in 1963-1975. The regression curve $y = 44.7\ e^{-0.76t}$ was calculated from the ten Danish stations in 1963-1967, (t = 0, Jan. 1, 1963), $y = 4.3\ e^{-1.08t}$ in 1971-1973 (t = 0, Jan. 1, 1971).

2.2. Strontium-90 in Sea-Water

No samples were obtained in 1975 from current sampling (cf. ref. 1) along the Greenland coasts. However, the DANA provided surface samples collected in August 1975 in West Greenland waters.

Table 2.2.1 shows the results of the ^{90}Sr and ^{137}Cs determinations. The ^{90}Sr levels are comparable with those of the previous years. The $^{137}Cs/^{90}Sr$ mean ratio was as high as 2.4 in these samples, i.e. equal to the mean found last year.

Table 2.2.1

Strontium-90 and Caesium-137 in surface sea water collected by the DANA at West-Greenland in August 1975

Position	pCi ^{90}Sr/l	pCi ^{137}Cs/l	Salinity o/oo
64°14'N 52°49'W	0.11	0.17 B	33.7
60°32'N 46°25'W	0.16	0.35	30.2
61°55'N 50°49'W	0.14	0.39	32.0
64°14'N 52°49'W	0.16	0.31 A	31.5
65°40'N 53°55'W	0.12	0.41	32.2

2.3. Strontium-90 and Caesium-137 in Terrestrial Animals

Reindeer samples were obtained through the Royal Greenland Trade Company. Table 2.3.1 shows the results.

Table 2.3.1

Strontium-90 and Caesium-137 in wild reindeer collected by the Roval Greenland Trade Company in 1975

Wild reindeer	Sample type	pCi ^{90}Sr/kg	pCi ^{90}Sr/g Ca	pCi ^{137}Cs/kg	pCi ^{137}Cs/g K
I	Meat	3.7	43	1013	315
I	Bone	-	40	-	-
II	Meat	2.8	28	442	104
II	Bone	-	23	-	-
III	Meat	7.8	43	288	93
III	Bone	-	38	-	-

Table 2.3.2

Strontium-90 and Caesium-137 in lamb collected by the Royal Greenland Trade Company in 1975

Lamb	Sample type	pCi ^{90}Sr/kg	pCi ^{90}Sr/g Ca	pCi ^{137}Cs/kg	pCi ^{137}Cs/g K
I	Meat	4.0	68	479	216
I	Bone	-	99	-	-
II	Meat	4.6	85	609	214
II	Bone	-	50	-	-
III	Meat	3.1	50	460	136
III	Bone	-	48	-	-

The mean levels in reindeer meat were 581 pCi ^{137}Cs/kg and 4.8 pCi ^{90}Sr/kg. In bone we found 34 pCi ^{90}Sr/g Ca. Fig. 2.3.1 shows the annual ^{90}Sr levels in reindeer (and musk ox bone) since 1961. The reindeer levels have decreased exponentially since 1967 with an effective half-life of 1.7 years. Figure 2.3.2 shows the ^{137}Cs levels in Greenland reindeer meat since 1961.

Three samples of lamb were obtained through the Royal Greenland Trade Company. The meat contained 3.9 pCi ^{90}Sr/kg (68 S.U.)

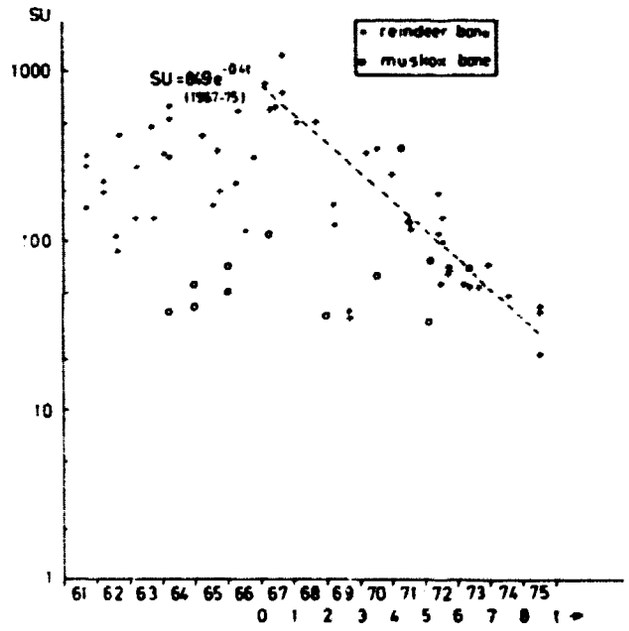

Fig. 2.3.1. Strontium-90 in reindeer and musk ox bone 1961-75. The two results from the autumn of 1969 were omitted in the calculation of the regression line: S.U. = 849 $e^{-0.4t}$ (1967-75).

and 516 pCi ^{137}Cs/kg (189 pCi ^{137}Cs/g K). The bone contained 66 pCi ^{90}Sr/g Ca. The levels for lamb were generally lower than those in 1974.

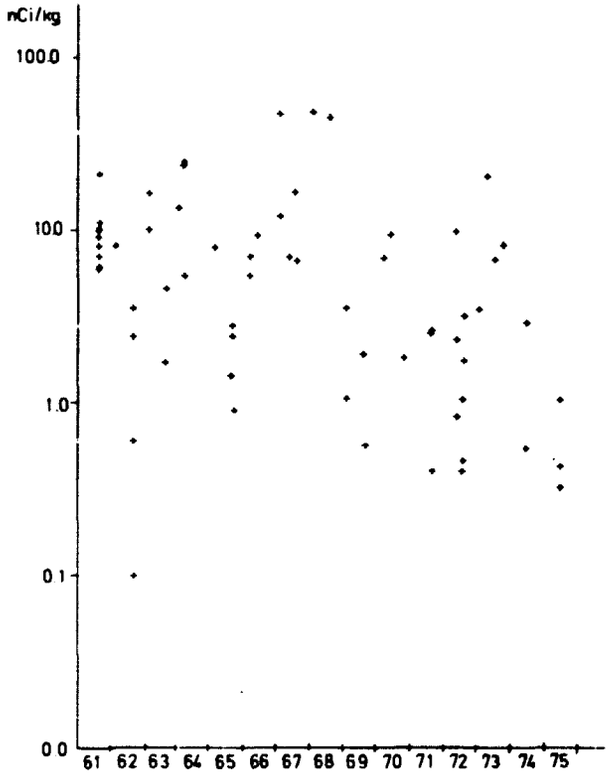

Fig. 2.3.2. Caesium-137 in reindeer meat from Greenland, 1961-75.

2.4. Strontium-90 and Caesium-137 in Sea Animals

The levels in cod and shrimps are shown in table 2.4.1. The mean levels were: 1.5 pCi ^{90}Sr/kg meat, 11 pCi ^{137}Cs/kg meat. A fresh water trout contained 25 pCi ^{90}Sr/kg meat and 40 pCi ^{137}Cs/kg and the bone contained 84 S.U.

Table 2.4.1

Strontium-90 and Caesium-137 in sea animals purchased through the Royal Greenland Trade Company in 1975

Species	Sample type	pCi ^{90}Sr/kg	pCi ^{90}Sr/g Ca	pCi ^{137}Cs/kg	pCi ^{137}Cs/g K
Cod	Meat	1.12 A	13.7 A	16.3	4.6
Shrimp	Meat	1.91 A	3.9 A	6.0 B	4.3 B

2.5. Strontium-90 and Caesium-137 in Vegetation

Lichen, moss, berries, and seaweed were collected along the Greenland coast during the summer. Table 2.5 shows the results.

The geometric mean levels in moss and lichen were 6400 pCi ^{90}Sr/kg and 23,000 pCi ^{137}Cs/kg. These levels are in good agreement with the values observed earlier (cf. fig. 2.5).

Table 2.5

Strontium-90 and Caesium-137 in vegetation samples collected in 1975

Location	Species	pCi ^{90}Sr/kg	pCi ^{90}Sr/g Ca	pCi ^{137}Cs/kg	pCi ^{137}Cs/g K
Sukkertoppen	Lichen I	6,100	4,700	25,000	-
Sukkertoppen	Lichen II	5,800	4,400	33,000	-
Sukkertoppen	Moss	7,400	3,000	14,000	-
Sukkertoppen	Crowberry	17.1	260	130	-
Prins Chr.sund	Crowberry leaves and twigs	1,400	500	9,700	-
Sukkertoppen	Crowberry leaves and twigs	5,700	710	-	-
Prins Chr.sund	Seaweed	82	7.6	37	1.4

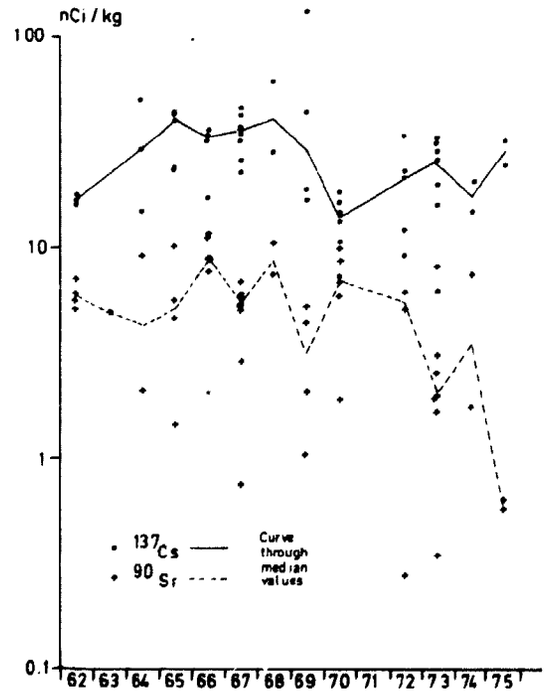

Fig. 2.5. Caesium-137 and Strontium-90 in lichen (fresh weight) collected along the Greenland coast 1962-75.

The ^{137}Cs levels generally decay more slowly than the ^{90}Sr levels in lichen (as well as in grass). For the period 1964-75 we estimated the effective half-life of ^{137}Cs in lichen from Greenland at 11 years.

2.6. Strontium-90 in Drinking Water

Quarterly samples of drinking water were collected from a number of locations in Greenland. Table 2.6 shows the results from 1975, and fig. 2.6 the results from four of the locations for the period 1962-1974.

Table 2.6

Strontium-90 in drinking water collected in Greenland in 1975
(pCi $^{90}Sr/l$)

Location	Jan.-Mar.	Apr.-June	July-Sep.	Oct.-Dec.
Danmarkshavn		1.47	1.81	1.75
Upernavik	1.02 B	0.93	0.85	0.18 A
Godthåb	0.72±0.14	0.78		0.64
Prins Chr.sund	3.42	1.17	0.59	3.32

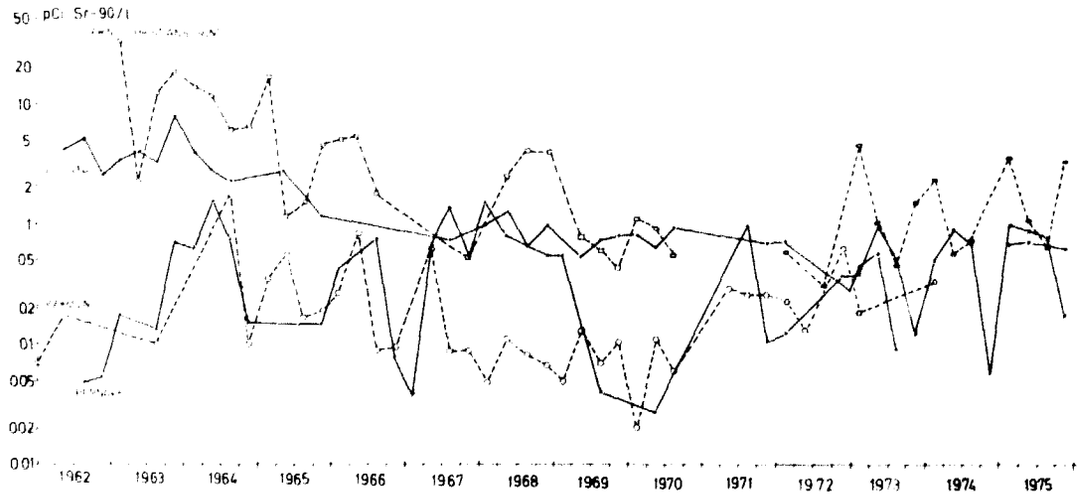

Fig. 2.6. Strontium-90 in Greenland drinking water, 1962-75.

As in previous years, we found it most expedient to choose the geometric mean of all figures, i.e. 1.05 pCi $^{90}Sr/l$, as representative of the mean level of ^{90}Sr in Greenland drinking water in 1975.

Fig. 2.6 shows that the difference between the various locations has been less pronounced in recent years.

3. ESTIMATE OF THE MEAN CONTENTS OF ^{90}Sr AND ^{137}Cs IN THE HUMAN DIET IN GREENLAND IN 1975

3.1. The Annual Quantities

The estimate of the daily per capita intake of the different foods in Greenland is still based on the figures given in 1962 by Professor E. Hoff-Jørgensen, Ph.D., in Risø Report No. 65[1].

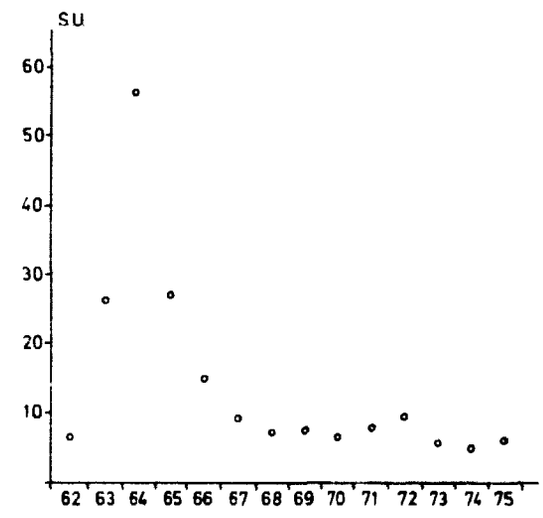

Fig. 3.1. Strontium-90 in Greenland diet, 1962-75.

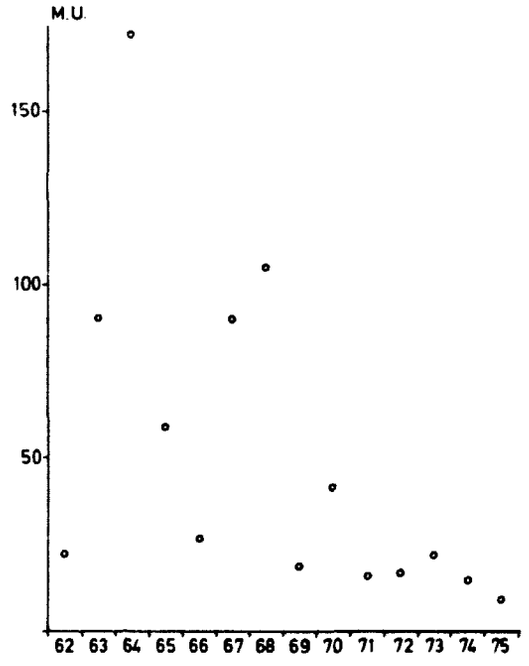

Fig. 3.2. Caesium-137 in Greenland diet, 1962-75.

3.2. Milk Products

All milk consumed in Greenland was imported as milk powder from Denmark. The mean radioactivity content in milk prepared from Danish dried milk produced in 1975 was 4.9 pCi ^{90}Sr/kg and 6.1 pCi ^{137}Cs/kg[2].

Cheese was also imported from Denmark and contained 34.7 pCi ^{90}Sr/kg and 4.4 pCi ^{137}Cs/kg.

3.3. Grain Products

All grain was imported from Denmark. It is assumed that only grain from the harvest of 1974 was consumed in Greenland during 1975. The daily per capita consumption was: rye flour (100% extraction): 80 g, wheat flour (75% extraction): 110 g, rye flour (70% extraction): 20 g, biscuits (rye, 100% extraction): 27 g, and grits: 25 g. The content of ^{90}Sr in these five products was 32, 6, 6, 24, and 16 pCi/kg respectively. Hence the mean content of ^{90}Sr in grain products was 17 pCi/kg. The content of ^{137}Cs in the five products was 51, 16, 25, 38, and 28 pCi/kg. Hence the mean content of ^{137}Cs in grain products was 31 pCi/kg.

The activity levels in rye flour (100% extraction), wheat flour (75% extraction), and grits were all taken from tables 5.9.1 and 5.9.2 in Risø Report No. 345[2]. The ^{90}Sr level in rye flour (70% extraction) was calculated analogously with the level in wheat flour (75% extraction), i.e. as one-fifth of the whole-grain activity. The ^{137}Cs content in rye flour (70% extraction) was calculated as one half of the whole-grain level in rye in analogy with the ratio between ^{137}Cs in whole wheat grain and in wheat flour (75% extraction)[2]. The ^{90}Sr and ^{137}Cs contents in biscuits were calculated by dividing the levels of the rye flour (100% extraction) by 1.35, since 1 kg flour yields 1.35 kg bread[2].

3.4. Potatoes, Other Vegetables, and Fruit

The Danish mean levels for 1975 were used[2] since the local production is insignificant compared with imports from Denmark.

The Danish mean levels were: in potatoes 3.7 pCi ^{90}Sr/kg and 6.6 pCi ^{137}Cs/kg, in other vegetables 10.6 pCi ^{90}Sr/kg and 3.2 pCi ^{137}Cs/kg, and in fruit 3.1 pCi ^{90}Sr/kg and 2.2 pCi ^{137}Cs/kg.

3.5. Meat

Nearly all meat consumed in Greenland is assumed to be of local origin. Approx. 10% comes from sheep, 5% from reindeer, 60% from seals, 5% from whales, and 20% from sea birds and eggs.

The activity in reindeer and lamb was estimated from 2.3.

Activity in seals and whales was estimated from table 2.4.1, Risø Report No. 325[1], while sea birds and eggs were estimated to have contained the same as in 1969, i.e. 0.14 pCi ^{90}Sr/kg and 90 pCi ^{137}Cs/kg. Hence the mean levels in Greenland meat from 1975 were 1.5 pCi ^{90}Sr/kg and 109 pCi ^{137}Cs/kg.

3.6. Fish

All fish consumed was of local origin, and the mean levels from 2.4 were used, i.e. 1.5 pCi ^{90}Sr/kg and 11 pCi ^{137}Cs/kg.

3.7. Coffee and Tea

The Danish figures for 1975[2] were used for coffee and tea, i.e. 25 pCi ^{90}Sr/kg and 37 pCi ^{137}Cs/kg.

3.8. Drinking Water

The geometric mean calculated in 2.6 was used as the mean level of ^{90}Sr in drinking water, i.e. 1.05 pCi ^{90}Sr/l. The

Table 3.1

Estimate of the mean content of ^{90}Sr in the human diet in Greenland in 1975

Type of food	Annual quantity in kg	pCi ^{90}Sr per kg	Total pCi ^{90}Sr	Percentage of total ^{90}Sr in food
Milk and cream	78	4.9	382	11.5
Cheese	2.5	34.7	87	2.6
Grain products	95.6	17	1625	48.8
Potatoes	32.8	3.7	121	3.6
Vegetables	5.5	10.6	58	1.7
Fruit	13.5	3.1	42	1.3
Meat and eggs	45.6	1.5	68	2.0
Fish	127.6	1.5	191	5.7
Coffee and tea	7.3	25	183	5.5
Drinking water	548	1.05	575	17.3
Total			3332	100

The mean annual calcium intake is estimated to be 560 g (approx. 200-250 g cæta praeparata). Hence the ^{90}Sr/g Ca ratio in Greenland total diet in 1975 was 6.0 S.U. and the daily intake 9.1 pCi ^{90}Sr.

Table 3.2

Estimate of the mean content of ^{137}Cs in the human diet in Greenland in 1975

Type of food	Annual quantity in kg	pCi ^{137}Cs per kg	Total pCi ^{137}Cs	Percentage of total ^{137}Cs in food
Milk and cream	78	6.1	476	4.5
Cheese	2.5	4.4	11	0.1
Grain products	95.6	31	2964	28.2
Potatoes	32.8	6.6	216	2.0
Vegetables	5.5	3.2	18	0.2
Fruit	13.5	2.2	30	0.3
Meat and eggs	45.6	109	4970	47.2
Fish	127.6	11	1404	13.3
Coffee and tea	7.3	37	270	2.6
Drinking water	548	0.3	164	1.6
Total			10523	100.0

The mean annual potassium intake is estimated to be approx. 1200 g. Hence the ^{137}Cs/g K ratio becomes 8.8 pCi ^{137}Cs/g K. The daily intake in 1975 from food was 29 pCi ^{137}Cs.

^{137}Cs content was as previously[1] estimated at 1/4 of the ^{90}Sr content, i.e. approx. 0.3 pCi ^{137}Cs/l.

Tables 3.1 and 3.2 show the diet estimates of ^{90}Sr and ^{137}Cs respectively.

3.3. Discussion

The most important ^{90}Sr source in the Greenland diet is still grain products, which contribute 48.8% of the total ^{90}Sr content in the diet. Drinking water came next in importance, contributing 17.3%. Approx. 75% of the ^{90}Sr in the food consumed in Greenland in 1975 originated from imported Danish food.

Meat is still the most important ^{137}Cs source in the Greenland diet, contributing 47.2% of the total content in 1975. Approx. 64% of the ^{137}Cs in the Greenland diet in 1975 came from local products.

As compared with the 1974 figures, the ^{90}Sr content in the total diet in 1975 was 24% higher than the 1974 level, while the ^{137}Cs level was approx. 53% of the 1974 level.

To estimate the maximum per capita intakes of ^{90}Sr and ^{137}Cs in Greenland in 1975 we again assume[1] that the only grain product consumed by a person is dark rye bread, and that he only eats reindeer meat. His daily intake of ^{90}Sr is thus 13 pCi (8.8 S.U.) and his ^{137}Cs intake 93 pCi/day (using the quantities in tables 3.1 and 3.2). At the lower limit we can imagine a person eating white bread and seal meat and drinking water with hardly any activity (e.g. water formed by the melting of old ice). In this case the daily intakes are 5 pCi ^{90}Sr (3.0 S.U.) and 13 pCi ^{137}Cs. Hence the ratios between the levels in the maximum and minimum diets become 2.9 for ^{90}Sr and 7.2 for ^{137}Cs.

The ^{90}Sr content of the Greenland diet was nearly equal to the estimated Danish mean content[2], and 53% of the Faroese level[3]. The ^{137}Cs level in the total diet in Greenland was 1.7 times that of the Danish diet and ten times lower than the Faroese diet level.

4. CONCLUSION

4.1.

The ^{90}Sr fall-out rates in 1975 were the following: Godhavn: approx. 0.3 mCi $^{90}Sr/km^2$; Godthåb: 0.5 mCi $^{90}Sr/km^2$; Prins Christians Sund: approx. 2.3 mCi $^{90}Sr/km^2$; Upernavik: 0.2 mCi $^{90}Sr/km^2$. The accumulated fall-out levels by the end of 1975 were estimated at approx. 26 mCi $^{90}Sr/km^2$ at Godhavn, 38 mCi $^{90}Sr/km^2$ at Godthåb, 139 mCi $^{90}Sr/km^2$ at Prins Christians Sund, and 15 mCi $^{90}Sr/km^2$ at Upernavik.

4.2.

The food consumed in Greenland in 1975 contained on the average 6.0 pCi $^{90}Sr/g$ Ca, and the daily mean intake of ^{137}Cs was estimated at 29 pCi. The most important ^{90}Sr contributors to the diet were grain products and drinking water, together accounting for approx. 66% of the total ^{90}Sr content of the diet. Caesium-137 originated mainly from meat (reindeer and lamb) and fish, contributing 60% of the total ^{137}Cs content of the diet.

4.3.

No ^{90}Sr analyses of human bone samples have hitherto been carried out on the population of Greenland. Considering the estimated ^{90}Sr levels in the diet, it seems probable[4], however, that the 1975 ^{90}Sr levels of humans in Greenland were on the average rather similar to those found in Denmark, i.e. the mean levels in human bone in Greenland were approx. 1-2 S.U. in newborn childre , 1-2 S.U. in infants, 1-2 S.U. in children and teenagers, and 1-2 S.U. in adults (vertebrae).

From diet measurements the ^{137}Cs content in Greenlanders was estimated at 20 pCi ^{137}Cs/g K.

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